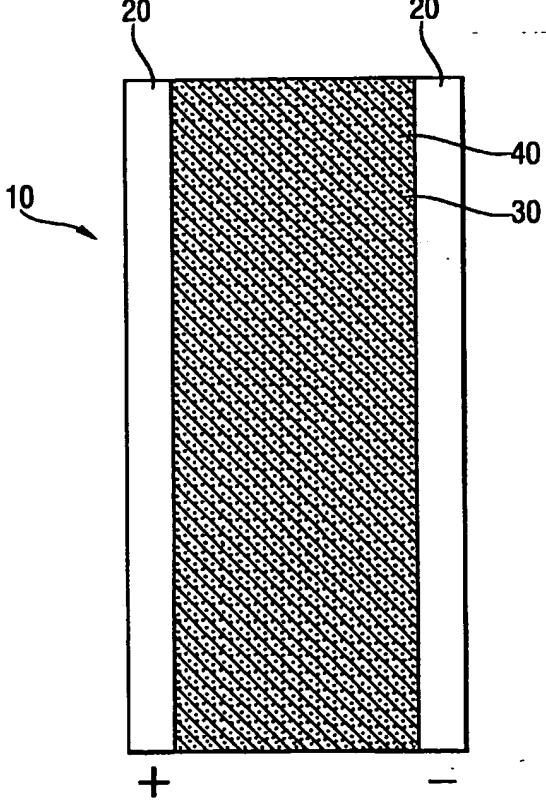


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<p>(54) Title: <b>AN ELECTROCHEMICAL ENERGY STORAGE MEANS</b></p> <p>(57) Abstract</p> <p>An electrochemical energy storage means with at least two electrodes and an electrolyte, a carrier material for the electrolyte being disposed between the electrodes, and the carrier material including a porous material in whose inner pore structure a perfluorinated surface-active substance is present:</p> 			

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## AN ELECTROCHEMICAL ENERGY STORAGE MEANS

This invention relates to an electrochemical energy storage means.

5        Electrochemical energy storage means in the sense of the invention are in particular capacitors, accumulators and batteries.

The present invention is based on the problem of providing a storage means which has a high capacity despite a low space requirement, is simple and cost-effective in production, reliable in handling and characterized by long 10 life.

The invention is based on the finding that this problem can be solved by 15 an energy storage means wherein the carrier material for an electrolyte used is a porous material modified with a substance which influences both the surface properties of the porous material and the surface tension and ionic conductivity of the electrolyte.

The subject matter of the present invention is an electrochemical energy storage means with at least two electrodes and an electrolyte, a carrier material for an electrolyte being disposed between the electrodes, and the carrier material including a porous material in whose inner pore structure a 20 perfluorinated surface-active substance is present.

Porous material in the sense of this invention refers to material having cavities in its structure which permit mass transfer. The cavities can be produced as pores or by the fibrous structure of the material.

The carrier material in the storage means is to hold the electrolyte and 25 simultaneously allow ion flow in the electrolyte between the electrodes. This can be ensured, firstly, by the carrier material being a porous material and, secondly, by providing a perfluorinated surface-active substance which is present in the inner pore structure of the material. The perfluorinated surface substance is suitable both for improving the surface properties of the material 30 and for influencing the properties of the electrolyte. The porous material can thus be wetted by the electrolyte and receive and hold it reliably. This ensures excellent electrolytic transport and outstanding mobility. This transport and mobility is of considerable importance for the ion flow in the electrolyte. The perfluorinated surface-active substance additionally increases the ion mobility in

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the electrolyte. Consequently the inventive storage means has an outstanding capacity.

The porous material is preferably a porous fluoropolymer. Use of a porous fluoropolymer involves the advantage of providing a material with high 5 chemical and thermal stability. Temperature resistance must be ensured since high temperatures can be present in the energy storage means e.g. upon charging and discharging at high current densities and melting of the carrier material must be avoided. The carrier material is additionally exposed to the 10 electrolyte and/or redox systems in the storage means. The electrolyte is normally a chemically active substance, e.g. a strong acid or base. The carrier material must therefore have sufficient chemical stability.

The presence of a perfluorinated surface-active substance in the inner pore structure of the porous fluoropolymer makes the latter wettable and receptive for the electrolyte. This wettability ensures a sufficient hold of the 15 electrolyte in the carrier material, in particular in the pores. A sufficient presence of electrolyte in the pores permits the ions to penetrate through the electrolyte-filled pores of the carrier material and thus high ion flow and high ion mobility, leading to low ohmic resistance of the storage means.

Chemical and thermal stability of the modified porous material and stable 20 adhesion of the substance to the porous material ensure a long life of the inventive storage means.

In a preferred embodiment the inner pore structure of the porous material is coated at least partly with the perfluorinated surface-active substances. Since the presence of the surface-active substance is realized in 25 the form of a layer, excellent ion flow can be maintained in the electrolyte by the pore structure, as compared to the pores being filled with perfluorinated surface-active substance. In addition, providing a layer on the inner surface of the pore structure does not reduce the receiving capacity of the carrier material for an electrolyte.

30 The perfluorinated surface-active substance preferably has at least four carbon atoms.

The perfluorinated surface-active substance can be perfluorinated carboxylic acid, perfluorinated sulfonic acid, salts of said acids or perfluorinated betaine. These substances are characterized in that they can cause reduced

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surface tension of the electrolyte even at low concentration and additionally have high chemical and thermal stability. The electrolyte or redox system is normally present in an aqueous solution. To ensure adequate reception in the pore structure and sufficient transport and mobility through the pore structure a 5 hydrophilic surface is therefore necessary. Use of the above-mentioned fluorosurfactants achieves outstanding hydrophiling of the carrier material. Furthermore these substances have a certain solubility in the electrolyte, which is of advantage for reducing the surface tension of the electrolyte.

- The porous material used in the inventive energy storage means is 10 preferably polytetrafluoroethylene (PTFE). This material has excellent chemical and thermal stability and can be produced with high porosity. This permits the thickness of the carrier material in the inventive electrochemical energy storage means to be kept low and thus the gap between the electrodes to be reduced. A small gap between the electrodes is desirable in particular with capacitors 15 since this increases the energy density of the capacitor. At the same time, however, the carrier material must permit reception of a sufficient quantity of electrolyte even at low thickness in order to allow good ion flow and ion mobility in the electrolyte between the electrodes. This can be ideally using PTFE by reason of the high porosity with which a PTFE layer can be produced.
- 20 Additionally the use of PTFE allows production of a carrier material layer with very constant small thickness and uniform structure. Due to these properties the PTFE carrier material can also serve as a reliable spacer between the electrodes. Furthermore a uniform ion flow through the pore structure is ensured, and disturbances due to irregularities in the carrier material excluded.
- 25 The use of PTFE as a porous fluoropolymer also ensures high flexibility, which is of advantage in particular in the production of the inventive energy storage means since it avoids damage to the carrier material due to breakage.
- One can further use PTFE copolymers or blends of PTFE homopolymers as the porous material.
- 30 ~~According to a further embodiment the carrier material can be a composite containing nano-scale ceramic.~~ The presence of this, e.g. ion-conductive, ceramic makes the carrier material take part in the ion flow in the electrolyte. This increases the total ionic conductivity and improves the efficacy of the energy storage means at a given porosity. The nano-scale ceramic is

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preferably present in a quantity of no more than 50 vol% based on the fluoropolymer. In these quantities the properties otherwise typical of ceramic, in particular the brittleness, do not yet take effect and adversely affect the properties of the carrier material.

5 The porous material used can further be fluoropolymers, in particular PTFE copolymers or blends as composites with thermoplastics. These thermoplastics are present in a quantity of 20 to 90 wt%, preferably 30 to 70 wt%, based on the fluoropolymer.

According to the invention the porous material has a porosity of more  
10 than 50%, preferably more than 60%, especially preferably more than 70%. Such high porosity of the porous material allows good penetration of the carrier material with the electrolyte and thus a high electrolyte content in the space between the electrodes. Furthermore, high porosity minimizes the volume  
15 fraction between the electrodes which is filled by the porous material and does not take part in ion flow. The high porosity of the material also has a positive effect on the active surface of the electrodes or the energy density and capacity  
20 of the energy storage means. With high porosity the contact surface between the carrier material and the electrode or the redox system is minimal so that the surface of the electrodes available for the storage process is not reduced unnecessarily.

In a further preferred embodiment the perfluorinated surface-active substance is present partly in the electrolyte. Use of a surface-active substance having sufficient solubility in the electrolyte not only promotes hydrophiling of the surface of the carrier material but additionally reduces surface tension in the  
25 electrolyte. This reduced surface tension contributes considerably to sufficient wetting of the carrier material and electrode. Additionally the presence of perfluorinated surface-active substance in the electrolyte improves the ionic conductivity of the electrolyte.

The electrochemical energy storage means according to the present  
30 invention is preferably a capacitor. Ionic conductivity of the electrolyte and good wetting of the electrodes are very important in particular with capacitors. The advantages of the invention are therefore optimally exploited in a capacitor, in particular an electrolytic capacitor.

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If the inventive electrochemical energy storage means is a capacitor, it consists of electrodes and a carrier material penetrated by the electrolyte. When voltage is applied to the electrodes an ion flow is caused in the electrolyte. The capacitance of such a capacitor is dependent on the active surface of the 5 electrodes and inversely proportional to the thickness of the electrochemical double layer, comprising the ionic electrolyte components in the carrier material, formed on the contact surface between electrolyte and electrode.

The active surface of the electrodes is determined by the contact surface between electrode and electrolyte. To increase the specific surface 10 area, the electrode can have a certain roughness or porosity which can extend into the nanometer range. The thus enlarged surface is to enter into contact with the electrolyte as far as possible. Dead places, e.g. due to air pockets or due to the contact of the carrier material with the electrode, are thus to be kept as small as possible. In the inventive energy storage means, the surface to be 15 activated is optimized by using a porous material with high porosity and a surface modified by a perfluorinated surface-active substance as a carrier material. The high porosity minimizes the contact surface between the carrier material and the electrodes, and the reduced surface tension of the electrolyte ensures sufficient wetting of the electrode. The available surface can thus be 20 optimally exploited.

The gap to be adjusted between the electrodes can also be optimized in the inventive energy storage means. The use of a porous material, in particular fluoropolymer, coated with a perfluorinated surface-active substance permits production of thin layers having a constant thickness and uniform structure. 25 This reliably avoids contact between the electrodes even with a thin layer of carrier material. Due to the high porosity and in particular the hydrophiling of the carrier material surface caused by the surface-active substance, a sufficient quantity of electrolyte can be received in the carrier material and undisturbed ion flow ensured even at a small thickness of the carrier material.

30 The perfluorinated surface-active substance furthermore does not reduce the ionic conductivity of the electrolyte.

The capacitance of such an inventive capacitor can thus assume high values.

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The carrier material, fluoropolymer, preferably used in the invention has the additional advantage of being temperature-resistant, thereby avoiding undesirable melting of the carrier material. An inventive capacitor also offers advantages in the choice of electrolyte to be used. The surface modified 5 porous fluoropolymer has outstanding chemical stability, and undesirable decomposition processes of the carrier material can be reliably avoided even in the presence of strong electrolytes.

The use of a porous fluoropolymer which has been treated with a perfluorinated surface-active substance thus has the following advantages for a 10 capacitor:

- the carrier material serves as a reliable spacer between the electrodes;
- electrolytic flow is optimized due to the high porosity and good wettability of the carrier material;
- the perfluorinated surface-active substance positively influences the ion flow and ion mobility in the electrolyte; and
- the carrier material has outstanding temperature resistance and chemical stability.

The enclosed Figure 1 shows schematically the structure of a possible 20 embodiment of a capacitor according to the present invention and will be described in the following:

Storage means 10 has two electrodes 20, e.g. of titanium, which can be subjected to voltage by connections not shown in the figure. Between the electrodes there is carrier element 30, e.g. expanded porous PTFE, coated with 25 a perfluorinated carboxylic acid, which is penetrated by electrolyte 40, e.g., sulfuric acid, and holds it in its pores.

In use, the porous fluoropolymer of this invention which has been treated with a perfluorinated surface-active substance is typically compressed by single or double side embossed or structured current collector plates. One 30 or more of the treated porous fluoropolymer materials of this invention may be compressed between the plates. The inventors have discovered that the carrier materials of this invention have unexpectedly very good sealing properties around the periphery of the carrier materials between the plates. In tests using isopropanol, a highly wetting fluid, the carrier material of this invention, which

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had been hydrophilized by the perfluorinated surface-active substance, provided a strong enough seal to prevent leakage of the isopropanol at reasonable sealing stresses.

5 This invention thus provides an integrated seal in a separator. The sealing separator may have the same construction as that set forth above.

~~✓~~ This has high value in any bipolar or single stack design, such as  
10 supercapacitors and fuel cells. Using the separator as a sealant eliminates additional sealing materials and the necessity of handling such additional sealing materials.

15 In an alternative embodiment of the present invention, a peripheral portion of the carrier material is not internally coated in its pores with the perfluorinated surface-active substance. Only the center portion of the carrier material that is exposed to the electrolyte is so coated. The non-coated periphery is the portion that is compressed and used to perform the sealing function.

20 In a further alternative embodiment taking advantage of the sealing properties of the carrier material of this invention, the peripheral area may be coated, partially or fully within the pores, with a thermoplastic, preferably an elastomer, and more preferably a fluoroelastomer or perfluoroelastomer. The center area of the carrier material of this embodiment is coated with the perfluorinated surface-active substance and the sealing periphery is coated with the thermoplastic in order to form the seal upon compression and use.

25 The attached Figure 2 further illustrates this aspect of the invention. A stack 70 of carrier materials according to this invention is shown in Figure 2. The center portion 50 of each of the materials is internally coated with the perfluorinated surface-active substance as described above. The peripheral portion 60 of the carrier material is either uncoated, or internally imbibed, partially or fully, with a thermoplastic. Peripheral portion 60 is the area of the carrier material that is compressed during use and performs the sealing function.

30 The porous material used in the inventive storage means preferably has the following characteristics. It should be electrically nonconductive and resistant to electrolyte and temperature. This resistance ensures long-term use

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of the storage means. Furthermore it should allow production of a thin flexible layer with a high porosity.

Porous materials to be used are e.g. fluoropolymers, polyethylenes, polypropylenes, glass fibers or zirconium-dioxides.

5 The formation of the porous structure is not limited to any certain technology. Pore-forming methods can include stretching, extracting a second component, dissolving out a component, applying the nuclear trace technique and pore formation by bubble formation. U.S. Patent no. 3,953,566 describes e.g. the production of expanded porous PTFE (ePTFE).

10 The porosity of the porous material used according to the invention is calculated by the following equation:

$$\text{Porosity} = (1 - \rho_m / \rho_t) \times 100\%$$

15 where  $\rho_m$  is the measured density of the material and  $\rho_t$  the theoretical density thereof.

Porous fluoropolymers which can be used in an inventive energy storage means are e.g. PTFE and PTFE copolymers. The PTFE can e.g. also be a type of PTFE with comonomers, referred to as "modified PTFE" (described 20 in more detail below). This designation also covers polymers in which the homopolymer is modified by copolymerization with ethylically unsaturated comonomers, their share being < 2 mass percent based on the copolymer. Examples of such comonomers are: ethylene, propylene, halogenated olefins such as hexafluoropropene, vinylidene fluorides and chlorotrifluoroethylene; 25 cyclic fluorinated monomers or perfluoroalkylvinylethers such as perfluoropropylvinylethers, perfluoromethylvinylethers or perfluorovinylethers with terminal carboxyl or sulfonic acid groups.

If the share of copolymer is more than 2 mass percent, the porous fluoropolymers are called fluorothermoplastics, fluoroionomers or 30 fluoroelastomers.

The starting material can also consist of fluorohomopolymers.

Fluorohomopolymers can be present as blends with low-molecular PTFE. The fluorohomopolymers are likewise mixable with tetrafluoroethylene (TFE) copolymers processed from the melt, such as

POROUS MATERIALS ..

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hexafluoropropylene/tetrafluoroethylene copolymers (FEP),  
perfluoroalkylvinyl/tetrafluoroethylene copolymers (PFA) or perfluorodioxole  
copolymers, e.g. available under the brand name Teflon AF from Dupont.

The porous material produced according to the U.S. 3,953,566 patent  
5 produces ePTFE films which have good air flow, are strong, handleable and  
uniform. This is accomplished, as described in U.S. Patent 3,953,566, by first  
compounding a polytetrafluoroethylene (PTFE) resin which is suited to produce  
a node and fibril microstructure upon stretching. The resin is blended with an  
aliphatic hydrocarbon lubricant extrusion aid, such as a mineral spirit. The  
10 compounded resin is formed into a cylindrical pellet and paste extruded by  
known procedure into a desired extrudable shape, preferably a tape or  
membrane. The article can be calendered to the desired thickness between  
rolls and then thermally dried to remove the lubricant. The dried article is  
expanded in a first stretch in the machine and/or transverse direction to produce  
15 an ePTFE structure characterized by a series of nodes which are  
interconnected by fibrils. The ePTFE article is then amorphously locked by  
heating the article above the crystalline melt point of PTFE (343°C), for  
example, 343-375°C. As described in U.S. Patent No. 5,814,405, the  
amorphously locked article may be then further stretched at a temperature  
20 above the crystalline melt point in at least the direction orthogonal to the  
direction of greatest expansion in the first stretch.

The resulting ePTFE materials are extremely uniform and possess a  
unique microstructure characterized as having highly elongated nodes  
interconnected by fibrils. The resulting porous materials also have a unique set  
25 of physical properties including high strength and low resistance to fluid flow, as  
well as a wide range of physical properties. It is quite surprising that this type of  
process would produce a highly uniform continuous film, especially with the  
large node, i.e., coarse, microstructures which are possible. Melt stretched  
membranes also have higher compression resistance.

30 A most preferred porous material allows the creation of open pore  
materials with low resistance to fluid flow by combining two types of stretching  
techniques, one before and one after amorphous locking. Initial expansion in  
the longitudinal direction is carried out prior to amorphous locking to set the  
scale of the microstructure (i.e., fibril and node dimensions). The uniformity of

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this expanded material is extremely high. This highly uniform microstructure is then amorphously locked by heating above the crystalline melting point of the highest melting PTFE present. This coalesces the nodes into sections of solid polymer. This locking step helps to preserve the uniformity of that initial 5 expansion step. In the final transverse stretching step, when the expanded material is heated to a temperature above the crystalline melt point of the PTFE resins present, the nodes elongate while the fibrils separate. The nodes do not continue to fracture and fibrillate upon further stretching as occurs in 10 expansions with non-amorphously locked PTFE tapes. Because no additional fibrillation takes place in this stretch step, very open, high flow, high strength membranes with extremely high specific inner surface area can be produced.

Traditional biaxial expansions of non-amorphously locked PTFE are extremely sensitive to differences in temperature and rate. Small differences in temperature or rate can lead to nonuniformities in the final membrane.

15 Surprisingly, the stretch above the crystalline melt point described above is much less sensitive to changes in temperature or rate. As a result, the membranes produced are much more uniform than traditional expanded PTFE products. The nodes of this structure are necessarily highly elongated and oriented. Aspect ratios on these nodes are greater than about 25 or 50:1 and 20 preferably greater than 150:1. This effectively produces a structure with solid polymer reinforced nodular ribs oriented transverse to the direction of initial expansion. These ribs prevent propagation of breaks or tears in the longitudinal direction. Such porous material provides extremely coarse microstructures where a large percentage of the total mass is retained in the nodes. This 25 results in a much higher mass article for a given openness or air flow thus yielding higher strength and durability. Matrix tensile strength can also be increased by increasing stretch ratio. By balancing the first and second stretch steps, a balance in strength in the x and y direction can be obtained.

30 The high strength of this preferred porous material allows the material to be compressed between collector plates in use without significantly closing the pores of the material. This is a significant advantage over the prior art. The more open structure of this porous material also allows more space for the perfluorinated surface-active agent and, more importantly, the electrolyte. This further improves ion mobility using this invention.

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The PTFE starting material for this preferred porous material can be any type of coagulated dispersion PTFE which lends itself to the formation of fibrils and nodes upon expansion. This is generally a polymer of high molecular weight.

5 A preferred starting material which produces uniform, strong, easily handled materials is a blend of high molecular weight fine powder PTFE homopolymer and a lower molecular weight modified PTFE polymer. This material is readily processed to form uniform expanded products with large nodes and long fibrils. By combining this blend of two PTFE resins with the  
10 process described above, a family of high flow, strong, uniform, handleable materials can be produced that are surprisingly useful for this invention.

Thus, the PTFE starting material used in the preferred process of making the porous material of the invention can be homopolymer PTFE or a blend of PTFE homopolymers. It can also be a blend of homopolymer and a  
15 PTFE copolymer in which the comonomer units are not present in amounts which cause the polymer to lose the non-melt-processible characteristics of pure homopolymer PTFE. By "fine powder PTFE" is meant that PTFE prepared by the "aqueous dispersion" polymerization technique. Both terms are well-known terms in the PTFE art.

20 The copolymers are called "modified PTFE homopolymers" in the art. The term "modified PTFE" is used here to describe a non-melt-processible polymer which is not a PTFE homopolymer but is a copolymer in which the homopolymer has been modified by copolymerisation with a copolymerisable ethylenically unsaturated comonomer in a small amount of less than 2%  
25 preferably less than 1%, by weight of copolymer. These copolymers have been called "modified" PTFE by those skilled in the art because presence of comonomer units does not change the basic nonmelt processable character of homopolymer PTFE. Thus, the term "modified" is used to connote that the good toughness, heat resistance and high temperature stability of the homopolymer  
30 is not altered when the homopolymer chain is interrupted by smaller trace units of the comonomer. Examples of comonomers include olefins such as ethylene and propylene; halogenated olefins such as hexafluoropropylene (HFP), vinylidene fluoride and chlorofluoroethylene; or perfluoroalkyl vinyl ethers such as perfluoropropyl vinyl ether (PPVE) and perfluoromethyl vinyl ether (PMVE).

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Preferably the comonomer is fluorinated and most preferably is HFP, PPVE, or PMVE. Neither PTFE homopolymer nor modified PTFE is considered to be elastomeric.

The homopolymer can also be blended with low molecular weight PTFE 5 known as micropowders, which are made by irradiation of high molecular weight PTFE, or are made by special TFE polymerization. The homopolymer can also be blended with melt-processible TFE copolymers such as FEP or PFA (hexafluoropropylene/tetrafluoroethylene copolymers or perfluoroalkyl vinyl ether/tetrafluoroethylene copolymer). Blends of two or more PTFE polymers 10 can be used, as can blends of PTFE with other fluoropolymers. No particular preference is made over the ratios of ingredients of these blends. One ingredient can be 5% or 95%, by either weight or volume.

In another embodiment even greater openness of structure can be achieved without sacrificing uniformity or handleability by carrying out an 15 additional longitudinal stretch after amorphous locking but prior to the final transverse stretch. The first post amorphous locking stretch in the longitudinal direction does little to further break up nodes but does elongate existing fibrils and separate existing nodes. By adding this stretching step nodes are separated and fibrils lengthened. The structure thus created has a significantly 20 larger average effective pore size. This added step does not reduce the overall uniformity of the final material. Adding this step greatly increases the total post amorphous locking stretch ratio possible with a given precursor. Typical constructions can be stretched to ratios between 9:1 and 12:1 in the transverse direction above 327°C. With the post locking longitudinal stretch, total stretch 25 ratios after amorphous locking of 24:1 and greater can be achieved. With a given precursor, Frazier number values have been increased by a factor of 25 while ball burst values decreased by a factor of only 3 when a 4:1 longitudinal stretch after amorphous locking was added.

In another alternative embodiment, porous fluoropolymers which can 30 furthermore be used are polymers additionally having nano-scale ceramic. This is preferably added to the polymer in powder form to the lubricant or as water based dispersion to PTFE dispersion.

Nano-scale ceramic powders in the sense of the invention include the  
group of metal oxides such as aluminum oxide, zirconium dioxide, silicon

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dioxide, titanium dioxide, zinc oxide and iron oxide as well as metal oxides with coatings (oxides, organic substances), mixed oxides, ferrites, metallic salts such as sulfates, sulfites, sulfides and phosphates. Naturally occurring materials, such as clays, kaolins, etc., can also be used. The particle size of the nano-  
5 scale ceramic powders is preferably 2 to 300 nm.

The porous fluoropolymer is preferably present in the form of a melt-stretched membrane, as discussed above. The microstructure of the porous fluoropolymer can consist of nodes and fibrils, only of fibrils, of fibril strands or bundles of fibrils or else of stretched nodes interconnected by fibrils. The  
10 preferred pore size of the fluoropolymer is in the range of 0.01 to 15 microns. The thickness of the porous fluoropolymer membrane is preferably between 1 to 1000 microns.

It is also within the scope of the invention to give the porous carrier material a multilayer design. One can use a sandwich of a porous  
15 fluoropolymer membrane with an ionconductive membrane or a system comprising a porous fluoropolymer membrane, a conventional ion-conductive membrane and a further porous fluoropolymer membrane. The conventional ion-conductive membrane can be e.g. a filled plastic membrane, the membrane being filled e.g. with perfluorinated ionomers, e.g. from a copolymer of  
20 tetrafluoroethylene and perfluorovinylether with terminal sulfonic acid groups, or e.g. with doped  $ZrO_2$ . The use of such a system or sandwich additionally improves the ion flow in such a conventional membrane between the electrodes. Symmetrical or asymmetrical membranes can be used.

The perfluorinated surface-active substance can be applied to or  
25 incorporated in the porous material by rolls, a dipping bath, spray technology and further known methods. Perfluorinated surface-active substance can also be present in the electrolyte and washed into the porous material therewith. Due to the low surface tension of the surface-active substance a monolayer of the compound can already suffice. This has the advantage that even extremely  
30 small-pore fluoropolymer membranes can be sufficiently hydrophiled without the pore structure being sealed. After treatment with the perfluorinated surface-active substance the porous fluoropolymer is preferably coated at least partly on the inner surface. However it is also within the scope of the invention to produce by the treatment an at least partial coating on both the inner and outer

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surfaces. The inner and outer surfaces of the porous fluoropolymer are preferably covered completely with the perfluorinated surface-active substance.

Initial porosity of the fluoropolymer and mean pore size are maintained.

Perfluorinated surface-active substances used in the sense of this 5 invention are in particular components which manifest a high state of order of the hydrophilic groups on the surface of the porous material and give the latter a hydrophilic property.

Preferred perfluorinated surface-active substances to be used in the 10 sense of the invention are ionic fluorosurfactants such as perfluorinated carboxylic acids or perfluorinated sulfonic acids, whereby the salts thereof can also be used. Perfluoropolyether with at least one terminal carboxylic acid group or the salt thereof can e.g. be used as a perfluorinated carboxylic acid or salt thereof. Furthermore one can use amphoteric fluorosurfactants such as 15 perfluorinated betaines or sulfobetaines. It is also conceivable to use a combination of a perfluorinated cationic resin with a perfluorinated anionic surfactant.

The perfluorinated part of the molecule can, depending on the 20 production method, be a) straight-chain, unbranched; b) terminal, branched; c) straight-chain with side groups; or d) highway branched. A chain length of the perfluorinated molecule part of four or more carbon atoms is generally preferred. These fluorosurfactants have high thermal and chemical stability which allows them to be used in aggressive media such as strong acids or bases, oxidizing or reducing solutions or at high temperatures. The nature of the polar molecule group of the surfactants furthermore influences the surface- 25 active properties of the fluorosurfactant. Fluorosurfactants are generally preferred in the sense of the present invention which reduce the surface tension of the electrolytic solution to values of < 28 mN/m. This presupposes a certain solubility of fluorosurfactant in the electrolyte.

The fluorinated surface-active substance is preferably mixed with a 30 solvent before being applied to the porous material. Water is preferred as a solvent according to the invention. However, other solvents are also possible such as alcohols alone or in combination with water.

The solvent is removed after treatment of the porous material e.g. by guiding the carrier material over heated rollers or by means of forced-air ovens.

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Treatment of the porous material with a perfluorinated surface-active substance results in a permanent modification with minimal application of the perfluorinated surface-active substance. The latter is preferably applied to the porous material in monolayers or in limited fashion in multilayers. Especially 5 permanent hydrophilic effects can be achieved depending on the selected modification variant. An oleophobic modification may be used for ePTFE membranes in a thin film as described in EP 587,988 B1. In such modification, the film is formed with equalized charge from at least one layer of a water soluble polycation and/or cationic synthetic resin, and a long chain surfactant or 10 a alkyl-substituted polyanion. The polycation is adsorbed on the substrate and complexed with the long chain surfactant or the alkyl substituted polyanion. The surfactant is an aliphatic unbranched long-chain fluorosurfactant.

The perfluorinated surface-active substance is held on the porous material by physical or electrostatic adsorption. This ensures excellent 15 adhesion of the substance to the porous material, thereby e.g. preventing the substance from being washed out and thus ensuring long life of the storage means.

The water- or alcohol-soluble perfluorinated surface-active substance preferably covers the total surface of the porous material. The thus treated 20 porous material contains enough free and readily accessible reactive groups which are in a position to make the porous material wettable with an electrolyte. Furthermore a sufficient solubility of the perfluorinated surface-active substance in the electrolyte is given so that the surface tension of the electrolyte can be sufficiently reduced. The result of modification of the porous material is a 25 changed more hydrophilic surface with an increased share of ionogenic groups in comparison to the starting material. The coating is therefore done using an excess of perfluorinated surface-active substance, part of the functional groups being used to manifest the hydrophilic property and the rest serving to reduce the surface tension of the electrolyte.

30 The electrolyte used can be an aqueous salt solution, aqueous solution of inorganic or organic acids and bases. One can also use gels e.g. from acids or bases in combination with inorganic oxides or salts such as aluminum oxide, zirconium dioxide, silicon dioxide, titanium dioxide, zinc oxide and iron oxide as well as metal oxides with coatings (oxides, organic substances), mixed oxides,

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ferrites, metallic salts such as sulfates, sulfites, sulfides and phosphates. One can also use polyfunctional organic compounds such as ionomers, polyelectrolytes or polyelectrolyte complexes. Organic electrolytes including a solvent and a salt may also be used. Typical solvents are propionitrile, 5 diethylether, dimethylsulfoxide, tetrahydrofuran, 1,2 dimethoxytheane, ethylene carbonate, propylene carbonate dimethyl carbonate, ethyl methyl carbonate, diethyl carbonate, acetonitrile, methyl formate and dimethoxyethane and mixtures and combinations thereof. Typical salts are cations of tetraethyl 10 ammonium, other tetraalkyl ammonium or ethyl methyl imidazolium or anions of trifluoromethyl sulfonimide, tetrafluoroborate, hexafluorophosphate, hexafluoroaresenate, trifluoromethane sulfonate and perchlorate.

The redox systems used in the inventive energy storage means can be e.g. redox systems of ruthenium, manganese or chromium.

15 The electrodes of the inventive energy storage means can be present in the form of plates or foils. It is also within the scope of the invention, however, to design the electrodes in other forms, such as stick electrodes.

The invention will be explained more closely in the following with reference to examples. The physical quantities were determined as follows.

## 20 Porosity

This was calculated by the following equation:

$$\text{Porosity} = (1 - \rho_m / \rho_t) \times 100\%$$

25 where  $\rho_m$  is the measured density of the material and  $\rho_t$  the theoretical density thereof.

## Mean pore size (Mean flow pore size, MFP)

A piece of membrane-with a 25 mm diameter was wetted with a 30 perfluoropolyether (Porofil). The wetted membrane was placed in a Coulter porometer II (Coulter Electronics Ltd.) and the mean pore size ascertained.

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### Surface tension

Surface tension was measured with the processor tensiometer K 12 from KRÜSS-GmbH Hamburg using Wilhelmy's plate method. A plate of exactly known geometry was brought in contact with the liquid. The force with 5 which the liquid moves along the wetting line on the plate was measured. This force is directly proportional to surface tension of the liquid.

### Conductivity

Conductivity measurements were performed on the microprocessor 10 precision conductometer LF 539 from Wissenschaftlich-Technische Werkstätten GmbH. The standard conductivity measuring cell TetraCon 96 was used.

### Example 1

A 65 micron thick membrane of expanded polytetrafluoroethylene (mean 15 pore diameter 0.40 microns, porosity 78%, GORE-TEX® membrane, obtained from W. L. GORE & Associates GmbH) was coated via a roll coater with a fluorosurfactant solution (7% FT 248 solution from isopropyl alcohol and water 1:1). The fluorosurfactant is available from Bayer AG and is  $C_8F_{17}SO_2ONH_4$ . The membrane was guided through a heated furnace (200°C) and freed from 20 the solvents. After coating, one obtained a membrane with a mean pore size of 0.41 microns. The coating weight was about 3 g/m<sup>2</sup>, the porosity was unchanged. Six-n-sulfuric acid wetted the membrane immediately.

### Example 2

25 The surface tension values of fluorosurfactants were measured in water and sulfuric acid.

In accordance with Example 1 further membranes were furnished with fluorosurfactants. The results are stated in Table 1. All furnished membranes are wettable by electrolyte (e.g. 33% sulfuric acid).

Table 1:

Surfactant	Concentration	Surface tension of 6n sulfuric acid mN/m	Surface tension of water mN/m	Mean pore diameter of membrane μm
	1	17.0	24.6	0.40
FT 800 (Bayer AG., potassium salt of perfluorooctane sulfonic acid)				
FT 248 (Bayer AG)	1	16.5	18.4	0.37
Hoe T 4260 (Hoechst Ag. sulfobetaine)	1	19.8	18.6	0.38
MF 201 (Ausimont, monodiphosphate of a perfluoro- polyether)	1	16.7	16.8	0.40

The surfactants FT 800 and MF 201 are insufficiently soluble in pure sulfuric acid or water. For measuring surface tension the stated concentration of surfactant was produced in water/isopropyl alcohol or sulfuric acid/isopropyl alcohol.

### Example 3

The membranes produced in Example 2 were installed in a capacitor (see Figure 1). The electrolyte was 33% sulfuric acid. Temperature dependence of ionic conductivity of the electrolyte bound in the membrane was measured. Additionally, surface tension was measured in the new state and after five months of use in the capacitor. As the results show, no decrease in performance occurred at high temperatures or in long-term use.

Table 2:

Membrane modification	Surface tension of 6n sulfuric acid in new state mN/m	Surface tension of 6n sulfuric acid after 5 months mN/m	Conductivity 15°C mS	Conductivity 50°C mS
FT 800	16.7	16.8	673	1092
FT 248	17.7	17.3	665	1087
Hoe T 4260	20.1	18.9		
33.6% Sulfuric acid	75.3 (Reference)	75.3 (Reference)	670	1092

The inventive energy storage means is preferably a double-layer capacitor. The carrier material also receives the electrolyte and holds it well with this capacitor. Due to the perfluorinated surface-active substance the electrodes are wetted well with the electrolyte and the total available surface activated.

Finally the inventive storage means can also advantageously be a battery.

In the widest sense the inventive carrier material can be used as an electrolytic storage means, separator or diaphragm in particular in electrochemical systems such as electrolysis or electrodialysis applications.

## Claims

1. An electrochemical energy storage means (10) with at least two electrodes (20) and an electrolyte (40), a carrier material (30) for the electrolyte (40) being disposed between the electrodes (20), and the carrier material (30) including a porous material in whose inner pore structure a perfluorinated surface-active substance is present.  
5
2. The energy storage means of claim 1, characterized in that the porous material is a porous fluoropolymer.  
10
3. The energy storage means of claim 1 or 2, characterized in that the inner pore structure of the porous material is coated at least partly with the perfluorinated surface-active substance.  
15
4. The energy storage means of claim 1, 2 or 3, characterized in that the perfluorinated surface-active substance has at least four carbon atoms.  
15
5. The energy storage means of any of the above claims, characterized in that the perfluorinated surface-active substance is a perfluorinated carboxylic acid, a perfluorinated sulfonic acid, a salt of one of said acids or a perfluorinated betaine.  
20
6. The energy storage means of any of claims 1 to 5, characterized in that the porous material is polytetrafluoroethylene.  
20
7. The energy storage means of any of claims 1 to 6, characterized in that the porous material is a PTFE copolymer.  
25
8. The energy storage means of any of claims 2, 6 and 7, characterized in that the carrier material is a composite containing nano-scale ceramic.  
25
9. The energy storage means of any of claims 2, 6 to 7, characterized in that the carrier material is a composite including thermoplastics.  
30
10. The energy storage means of any of claims 1 to 9, characterized in that the porous material has a porosity of more than 50%.
11. The energy storage means of 10, characterized in that the porous material has a porosity of more than 70%.

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12. The energy storage means of any of claims 1 to 11, characterized in that the perfluorinated surface-active substance is present partly in the electrolyte.

13. The energy storage means of any of claims 1 to 12, 5 characterized in that it is a capacitor.

14. The energy storage means of claim 1 wherein said carrier material has an internal microstructure consisting essentially of a series of nodes interconnected by fibrils, said nodes generally aligned in parallel, being highly elongated and having an aspect ratio of 25:1 or greater.

10 15. The energy storage means of claim 1 wherein said perfluorinated surface-active substance is soluble in said electrolyte.

16. The energy storage means of claim 1 wherein said carrier material has a center portion and a peripheral portion and said perfluorinated surface-active substance is present only in said center portion.

15 17. The energy storage means of claim 1 wherein said carrier material has a center portion and a peripheral portion and said perfluorinated surface-active substance is present only in said center portion and a thermoplastic is present in said peripheral portion.

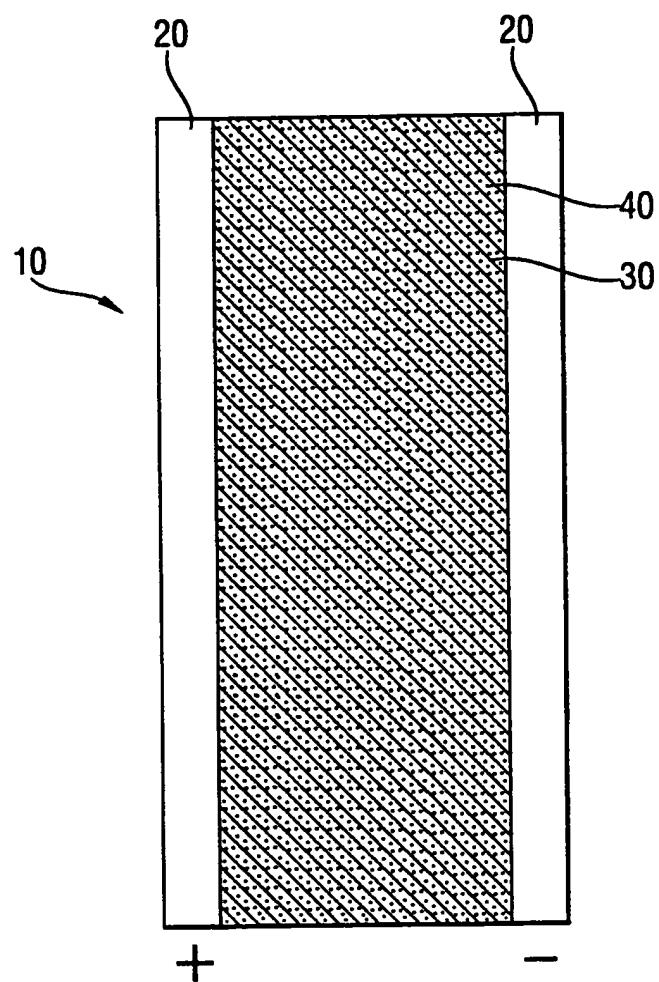
18. The energy storage means of claim 17 wherein said 20 thermoplastic is perfluoroelastomer.

19. The energy storage means of claim 16 wherein said peripheral portion is adapted to form a seal with current collector plates disposed on opposite sides of said carrier material.

20. The energy storage means of claim 17 wherein said peripheral 25 portion is adapted to form a seal with current collector plates disposed on opposite sides of said carrier material.

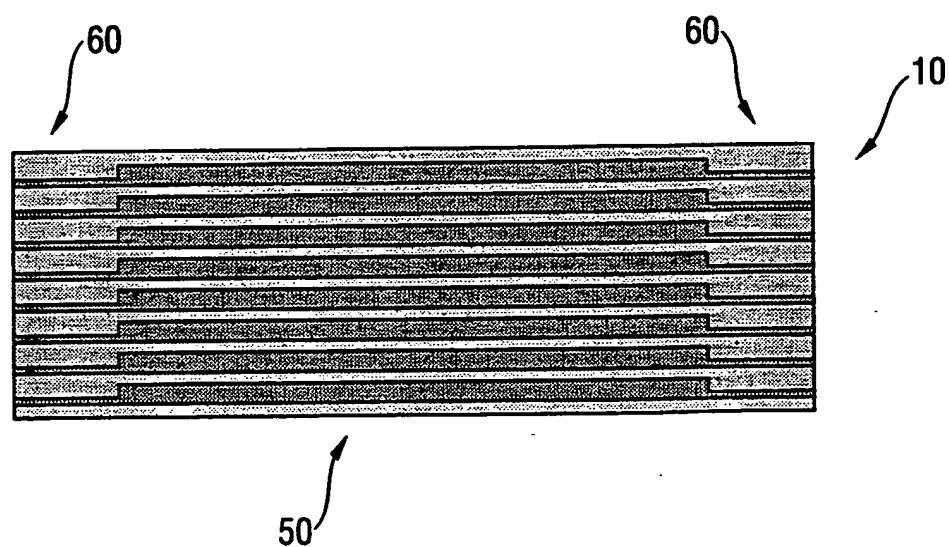
21. The energy storage means of claim 1 wherein said carrier material forms a seal at its periphery upon compression between current collector plates during assembly.

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**Fig. 1**

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**Fig. 2**

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/EP 98/06032

**A. CLASSIFICATION OF SUBJECT MATTER**  
 IPC 6 H01M6/18 H01G9/02

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H01M H01G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>EP 0 718 903 A (JAPAN GORE TEX INC)    26 June 1996</p> <p>see column 1, line 3 - line 8    see column 5, line 43 - line 47    see column 6, line 36 - column 7, line 3</p>	1-7, 10-12, 15-17, 19,20
X	<p>PATENT ABSTRACTS OF JAPAN    vol. 016, no. 540 (P-1450),    10 November 1992    &amp; JP 04 204522 A (TONEN CORP),    24 July 1992    see abstract</p> <p>—/—</p>	1,3,4, 12,13

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

\* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "Z" document member of the same patent family

Date of the actual completion of the International search

25 January 1999

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## INTERNATIONAL SEARCH REPORT

Int	ional Application No
PCT/EP 98/06032	

## C(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>DATABASE WPI  Section Ch, Week 9509  Derwent Publications Ltd., London, GB;  Class A85, AN 95-064422  XP002090994  &amp; JP 06 342666 A (ASAHI KASEI KOGYO KK)  , 13 December 1994  see abstract</p> <p>—</p>	1-6, 10-12, 15
X	<p>PATENT ABSTRACTS OF JAPAN  vol. 018, no. 458 (E-1596), 25 August 1994  &amp; JP 06 151249 A (NITTO DENKO CORP),  31 May 1994  see abstract</p> <p>—</p>	1-6, 13
P, X	<p>WO 98 11614 A (JAPAN GORE TEX INC ;GORE  ENTERPRISE HOLDINGS INC (US))  19 March 1998  see page 5, line 13 – line 17; claims  1,2,17  see page 11, line 16 – line 22</p> <p>—</p>	1-7, 9-20
P, X	<p>US 5 795 668 A (BANERJEE SHOIBAL)  18 August 1998  see column 8, line 26 – line 34; claim 1  see column 5, line 29 – line 60  see column 6, line 8 – line 14  see column 9, line 52 – line 67</p> <p>—</p>	1-7, 9-11

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International Application No

PCT/EP 98/06032

Patent document cited in search report	Publication date	Patent family member(s)			Publication date
EP 0718903	A	26-06-1996	JP	8162132 A	21-06-1996
			JP	8329962 A	13-12-1996
			JP	8213027 A	20-08-1996
WO 9811614	A	19-03-1998	JP	10092444 A	10-04-1998
			AU	4268797 A	02-04-1998
US 5795668	A	18-08-1998	NONE		